Experimental Investigation of Fluid-Mobile Element Transport in the Upper Mantle

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Status Report:

It is a widely held view that, in subduction zones, an H₂O-rich fluid derived from dehydration of the subducted oceanic crust infiltrates the lower portions of the mantle wedge, depressing the peridotite solidus and triggering partial melting. This "subduction component" is also thought to be responsible for enriching arc magmas in fluid-mobile trace elements. However, results from in-situ analyses of accessory minerals in eclogites suggest that mass transfer from the subducting slab to the mantle wedge driven by the breakdown of hydrous phases in the altered oceanic crust may not be entirely correct. Hydrous accessory minerals such as zoisite, phengite, and allanite retain "fluid mobile" elements in the subducting oceanic crust even after severe dehydration at eclogite facies conditions, suggesting that dehydration and geochemical fluxes from slab to the mantle wedge are decoupled. Further, models for the thermal structure of subduction zones that incorporate temperature- and/or stress-dependent viscosity for the mantle wedge predict temperatures at the base of the wedge in excess of the H₂O-saturated solidi of basalt and sediment. These lines of evidence favor low-degree partial melting of the slab at H₂O-saturated conditions as the primary mechanism for mass transfer. As a test of this hypothesis, we are carrying out an experimental determination of how fluid-mobile trace elements such as Rb, Sr, Ba, La, Pb, Th, and U are distributed between accessory minerals and aqueous fluids at pressure and temperature conditions corresponding to dehydration of the subducting oceanic crust (2.0 GPa, 600 °C to 3.0 GPa, 750°C). Results from these experiments will allow a quantitative evaluation of the efficiency with which these minerals retains trace elements during dehydration at eclogite facies conditions and, thereby, provide new insights into the role of fluid flow as an agent of mass transport beneath volcanic arcs.

The initial phase of our work involved synthesizing the starting material and carrying out experiments to test various capsule materials and designs. The starting material for the experiments consists of a synthetic mixture of SiO₂, Al₂O₃, and CaO, in a proportion to crystallize equal parts of the minerals lawsonite (CaAl₂Si₂O₈.2H₂O), zoisite (Ca₂Al₃Si₃O₁₂(OH)), and kyanite (Al₂SiO₅). In order to stabilize lawsonite and zoisite, both of which contain water in their structure, liquid H₂O is added to the capsule by microsyringe just prior to the start of an experiment. The trace elements K, Rb, Sr, Ba, Pb, Th, and U have been added to the starting material at a concentration of 100 ppm each using ICPMS standard solutions. Experiments have been carried out using a solid medium piston cylinder device at pressures of 2.0 and 3.0 GPa. equivalent to depths of ~66 to 100 km within the earth, and a temperature of 700 °C. Our initial choice of capsule material was Ag, which is relatively inexpensive and does not interact chemically with the silicate portion of the experiment. Trial runs carried out using these capsules showed that Ag reacts with the H₂O in the capsule to form Ag₂O, leading to highly oxidizing conditions and a progressive loss of H₂O from the capsule due to deterioration of the seal between the lid and the capsule. To remedy this situation, we have begun using capsules fabricated from Ni. Because Ni reacts with the silicate portion of the experiment, we designed a capsule with an inner sleeve made from Pt. This capsule design is both more expensive and labor intensive to fabricate, but produces a tightly sealed capsule and well-controlled oxygen fugacity conditions. The latter is critical to the success of the experiments because uranium can occur as either U⁴⁺ or U⁶⁺, depending on the ambient oxygen conditions, and this will have a strong effect on partitioning behavior. The next stage in this work involves carrying out experiments at

pressure and temperature conditions corresponding to dehydration of the subducting oceanic crust (2.0 GPa, 600 °C to 3.0 GPa, 750°C), and determining the concentrations of trace elements in lawsonite, zoisite and kyanite by secondary ion mass spectrometry (SIMS) using the Cameca 3f ion microprobe at WHOI.

Our most successful experiment to date, carried out at 3 GPa, 700 °C, is shown below in a back-scattered electron image. The large, elongate mineral is kyanite, as identified by comparing diffraction patterns (generated from an electron backscatter diffraction detector on a standard SEM) with a database of phase orientations (Channel 5+ software). Scale bar is 10 microns.

